BONE CONDUCTION OF SOUND IN CETACEA AND ITS RELATION TO INCREASED BONE CONDUCTION IN HUMAN BEINGS.*

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One of the most important symptoms of chronic middle ear catarrh is the relative and absolute increase of bone conduction found in that condition. Many of the tests on which the differential diagnosis depends, such as Weber's, Schwabach's, etc., are based upon it; yet nowhere is there agreement among otologists as to its cause. There appears, moreover, to have been done little experimental work with a view of explaining it.

Several theories are advanced concerning the phenomenon. First is that of Bezold, that in consequence of the changes within the middle ear, although the mobility of the conducting chain of ossicles may be interfered with, yet the tensing of the fibers of the ligamentum annulare renders possible an easier conduction of sound waves coming through the bone to the foot plate of the stapes. A second explanation is that the sound waves coming through the bone are transmitted directly to the structures within the cochlea. Still another is that under conditions of closure of the external auditory meatus, the air within the tympanum receives the sound vibrations from the bony walls of the cavity and transmits them increased in force to the foot plate of the stapes, the closed cavity acting as a resonance box.

In making some studies on cetacea, it occurred to the writer that in the anatomical structure of the ears of these animals we might find an explanation of the increased bone conduction of sound at least under some circumstances. Lest anyone question the fact of whales having hearing on account of our having no experimental proof, I shall here call attention to two evidences of it. Whalers and others having to do with these animals all testify as to their ability to hear water-borne sounds. In hunting the animals no precaution need be taken as to air borne sounds such as conversation. Sounds which would be carried through the water, however, such as splashing of oars, pano-mastoid, which appears largely on the surface of the skull in a notch between the squamosal and exoccipital. The presence of this large mass, an outgrowth of one of the bones related to the organ of hearing, should be noted, as it had in all probability much to do with the ability of the animal to hear.

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The two bones, tympanic and periotic, are united in one other place by bony union, a small area farther rostrad on the outer border of the bulla. Elsewhere they are separated by fissures of varying width. Together they lie entirely outside the skull in a space bounded by the basi-occipital, the exoccipital and the squamosal, and they are buried in a mass of cavernous tissue enclosing blood and air spaces.

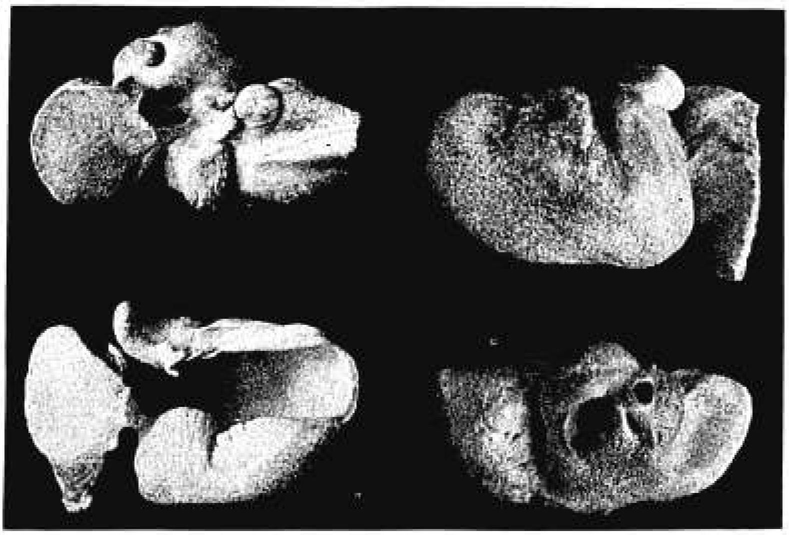

Fig. 1—Periotic and tympanic bones of Ziphius Cavirostris.

In the mystacocetes the arrangement of the bones is much the same as described for the odontocetes. The tympanic forms a semi-cylindrical bulla, having a similar over-rolled internal and irregular external edge in a deep groove of which is set the membrane tympani. To one marked difference attention should be called. The process of the tympanic referred to as the tympano-mastoid is absent in the mystacocetes. Its place is taken by a true large mastoid process, a portion of the periotic, which appears on the surface of the skull between exoccipital and squamosal bones just as in other mammals. Tympanic and periotic have two areas of bony union, slight in extent. The two together are only loosely joined to the other panum. The walls of this canal are firm, fibrous structure, of moderate thickness and without cartilage as far as could be ascertained. The mouth of the canal and at first its lumen are so minute as to forbid probing. Approaching the tympanum, the lumen expands in a trumpet-shaped manner, though still of insignificant size.

The tympanic membrane is an exceedingly thin sheet, faces dorso-mesad and is attached to the caudal and ventral borders of the notch it occupies. Rostrad, it passes beyond the border to find attachment in a groove on the ental surface of the sigmoid process in the manner described by Denker for Phocaena. Dorsad it is attached to the fibrous band which bridges over the space between the anterior and posterior conical processes. As far as could be ascertained, the surface of the membrane is slightly concave ectad, as in other odontocetes and in young baleen whales. Its inner surface is connected to the malleus by a triangular fold of mucus membrane.

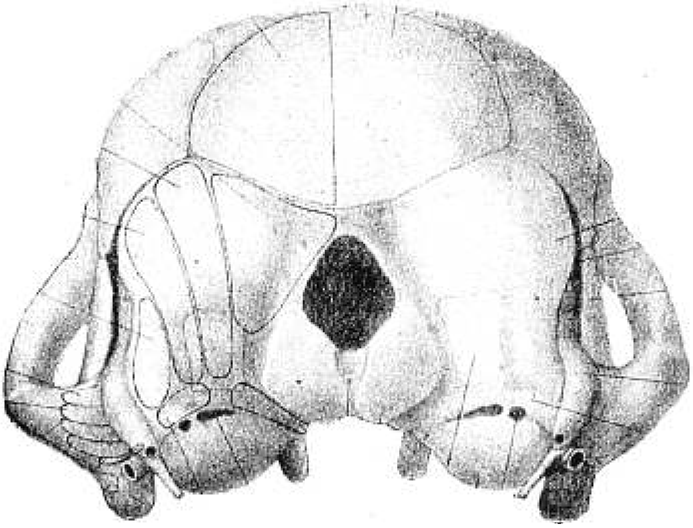

Fig. 3—Balaenoptera Borealis. Foetal skull.

The tympanic cavity, lying between the periotic (dorsad) and the broad rolled-over mesal border of the os tympanicum (ventrad) is a comparatively limited space, owing its dorso-ventral extension chiefly to the hollowing of the tympanic surface of the periotic. It has, however, communications with extensive air spaces lying beyond the borders of the limiting bones.

The cavity, in its natural state, is occupied by a mass of thick tissue which lines its walls and nearly fills it, in this manner concealing the ossicles. Wherever the os tympanicum and periotic fail to meet it fills in the space between them, and is continuous with the mass of cavernous tissue in which the whole complex lies buried. So it, too, is undoubtedly of cavernous nature. It fills in the hollow of the bulla and extends into the excavation beneath the inverted mesal border of that structure, also into the excavation of the tympano-mastoid. This cavernous tissue is probably of importance in regulating the pressure within the middle ear when the animal is submerged.

On the removal of the cavernous tissue the structure of the middle ear comes into view. The inner wall (or dorsal wall, as it is here) presents, caudad, a short rostro-caudal groove bordered by prominent ridges, the channel for the seventh nerve.

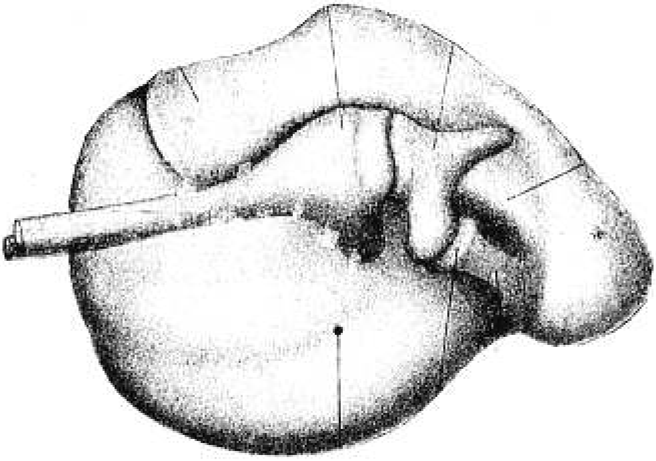

Fig. 4—Balaenoptera Borealis. Left otic capsule, external view.

Mesad of the groove is a ridge which is overlain by the stapedious muscle, and, just at its termination, the stapes is firmly secured but not ankylosed in the fenestra ovalis. Rostrad of this is a large depression occupying half the width of the tympanic surface of the bone. When the various parts are in their natural position this depression is occupied by the head of the malleus. Jutting underneath the orifice of the ductus fallopii is a prominent spicule, against which rests the short process of the incus. No tensor tympani muscle was discovered though a groove for one has been noted (Schulte)[3] in the position in which we should expect to find that muscle. It is of interest to state here that in another odontocete (Tursiops) a distinct tensor tympani muscle has been found by the author—a fact not hitherto noted and by some specifically denied (Denker). It is here much less defined than in baleen whales.

The ossicles, in their general form, do not differ from the usual mammalian type. The malleus has a proportionally large head, which lies in the depression in the periotic already described. The manubrium mallei is fused to the os tympanicum along the border of a narrow cleft in its lateral margin. The usual saddle-shaped articulation unites malleus and incus. The latter bone is distinguished by the fact that the two processes are of equal length, although the processus longus is the thicker. The processus brevis, at its tip, meets a small tubercle which juts out from the crista facialis dorsad to the fenestra ovalis. The stapes is not fenestrated and sits firmly in the oval window. The non-fenestrated condition is doubtless secondary, as Denker describes small depressions in the stapes of Phocaena which indicate the existence of a fenestra, and the author has observed the same in other odontocetes, namely, Ziphius and Tursiops.

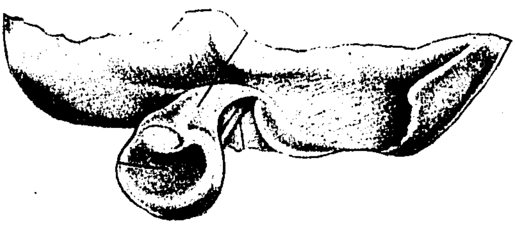
Fig. 5—Kogia Breviceps. Mesial view of fragment of tympanum with malleus attachment.

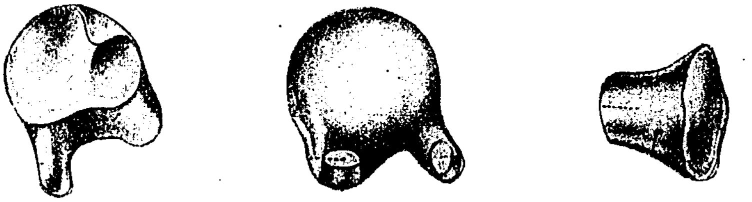
Fig. 6— a. b. c.
Kogia Breviceps—(a) Lateral view of incus. (b) Mesial view of incus. (c) Stapes.

The tympanic opening of the facial nerve lies just above the oval window. At this point the nerve turns sharply dorsad and takes a straight course through the periotic. Thus the geniculate ganglion must lie within the tympanic cavity. This is due to the non-development of that portion of the tegmen tympani which in other mammals (as for instance, man) cover in the facial canal for the latter part of its course in the tympanum. A minute canal for the great superficial petrosal nerve passes rostrad between tegmen tympani and periotic, as it has

It must be remembered that the above description applies only to an immature animal. In the adult, Beauregard[4] has found that the drum membrane bugles outward into the external auditory meatus like the finger of a glove, and in large part loses its resemblance to the ordinary mammalian drum membrane. In adult Balaenoptera also, the inner end of the auditory canal was found by Lillie[5] to be occupied by a ceruminous plug.

The cavum tympani is a bowl-shaped cavity having dorsal and ventral walls which meet in a sharp angle at their margins. The ventral wall contains in the lateral area the membrane tympani surrounded by the crescentic os tympanicum. The rest of the ventral wall is made up of the fibrous bulla which fills in the space between os tympanicum and the marginal attachment of the bulla.

The dorsal wall of the tympanic cavity is made up of the otic capsule centrally placed, and circumferentially of a ring of fibrous tissue which connects the petrosum to the surrounding bones. As it presents itself after removal of the os tympanicum and bulla, it is seen to be covered by a layer of thick tissue which completely conceals the underlying cartilages and almost fills the cavity. In the outer area of the cavity this structure throws folds about the ossicle and only on its removal can they be examined. The formation of this tissue shows it to be of a cavernous nature (Beauregard).

The tuba auditiva passes from the choana laterad between hamular and vaginal processes of the internal pterygoid and penetrates the wall of the bulla obliquely. Its entrance into the tympanic cavity is at the rostral circumference of the same in the angle formed by the meeting of ventral and dorsal walls. The opening is a crescentic slit capable of valveo-like closure. The tube is very short, merely an oblique passage through the fibrous wall of the bulla. The expansion of its distal end into the scaphoid fossa is not yet indicated.

The ossicles are typically mammalian, their arrangements Meckel's cartilage passes beneath the edge of the tympanic bulla, caudad and slightly dorso-laterad, closely roofed over by the tegmen tympani. Mesad to its shaft is the belly and tendon of the tensor tympani muscle. Within the tympanic cavity, the cartilage expands into a fairly large caput mallei, and forms a mesad projection, the manubrium to the base of which is attached the tensor tympani. A groove in its surface completely encircles the caput, close to the edge of the articulation with the incus. The border itself expands, thus increasing the depth of the groove.

The incus has a triardiate form. On the well-developed body is a saddle-shaped articular surface for the malleus. The processus brevis is stout and of large size. Its extremity is in contact with the crista parotica, to which it is firmly attached by a ligament. The processus longus, which actually is shorter than the brevis, is also bulky in form. It is directed ventrad to articulate through an os articulate with the apex of the arch of stapes.

The stapes, which are lodged in a deep fossula, does not fill with its foot plate the large fenestra, but is united to its circumference by a rather broad annular ligament. The bone closely agrees with the adult form; its arch is high and narrow, the limbs thick, the foramen small.

Comparing these two forms of cetacea we see that in regard to the absence of the external ear and the small size of the external auditory canal, they agree. The odontocetes lack, to be sure, the plug of cerumein found in the canal of the mystacocetes, but even in their case it cannot be imagined that any sound can reach the drum membrane through that passageway. In both alike the drum membrane is disassociated from the ossicles except for the prolonged "triangular ligament." Denker has satisfactorily demonstrated that no movement can be transmitted from drum membrane to ossicles, and also that movement of the ossicles independent of the os tympanicum is impossible.

The arrangement in the tympanum also shows properties in common. A typical mammalian chain of ossicles is found buried in a mass of cavernous tissue. The air space communicates with a series of surrounding air spaces through the intervals between os tympanicum and os petrosum. Of these air spaces, one, the cranial, is formed by a huge expansion of the Eustachian tube. All are capable of inflation from the pharynx. The comparatively loose attachment of the bones of hearing to the rest of the skull is a condition found in all whales. Finally attention is called to the presence on the surface of the skull of a large bony process coming off from the os tympanicum in the case of odontocetes, from the os petrosum in the mystacocetes.

What conclusions then can we draw from the anatomical structure as to hearing in cetaceans? We have presented to us an auditory apparatus, typically mammalian, designed to receive air-borne sounds modified to one designed to receive water-borne sounds. The external meatus has been practically closed, the drum membrane fixed and the ossicles rendered immovable through fusion of the malleus to the os tympanicum. Sounds are evidently transmitted to the cochlea through the solid tissues of the head. The possibility of this is increased because in both forms the auditory bones themselves present on the surface of the skull a considerable bony process. In both, moreover, the periotic and tympanic are but loosely connected to the other bones of the skull. Thus they can receive only such sound waves as impinge directly on themselves. Since the malleus is firmly fused to the tympanic it would share the vibrations of that bone, transmitting them through the other ossicles to the oval window. This is probably the explanation of hearing in cetacea, that sound waves impinging either on the tympano-mastoid in odontocetes, or the true mastoid in mystacocetes, are transmitted through the chain of ossicles to the cochlea, the endolymph being put into motion through the foot plate of the stapes as in other mammals.

Some authorities maintain that the sound waves reach the receptive organs in the cochlea directly through the walls of the periotic bone. In this connection it is important to recall that whereas such vibrations might provide for a vague perception of sound, they would hardly provide for the interpretation of sound which we are probably justified in thinking depends on an orderly succession of waves in the endolymph from fenestra ovalis to fenestra rotunda. This could be provided for only by vibrations coming through the foot plate of the stapes.

It will now be further recalled that the tympanic and periotic are surrounded by numerous cells capable of distension with air. This is undoubtedly set into motion by the vibrations of the bones of hearing and we may suppose that these air cavities form a kind of sounding box, which increase the sound waves. The air cells then are an important aid in hearing.

We may now consider the light which the mode of hearing in cetacea throws on the clinical symptom of increased bone conduction in deafness due to disease of the middle ear. It will be seen at once that any change which would connect the ossicles more firmly to the tympanic ring, approaching the complete fusion found in whales would increase bone conduction. A tense, thickened, rigid drum membrane would do this. We could also accept Bezold's idea that it is a thick, tense ligamentum annulare, transmitting vibrations to the foot-plate of the stapes, which in some cases explains the phenomenon under discussion. This would be the condition following a radical mastoid operation. Another theory may now be mentioned. When the external canal is lightly blocked, bone conduction is increased. This is explained by conceiving the air filled cavity with bony walls to be a sounding box. This is just what we have present in cetacea. In this connection it may be said that the variation in the size and number of the cells present in the human mastoid process may very well be an explanation of the variation in the response to tests of bone conduction found in seemingly similar cases of deafness.

We will see then that in cetacea we have all the elements normally present which have been advanced to explain the symptom of increased bone conduction in the diseased ear of human beings, and the anatomical arrangements there found could certainly support the explanations of the phenomenon advanced.

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The Diagnostic Value of Lowered Bone Conduction in Syphilis.

W. H. Goeckerman, R. A. Barlow and J. H. Stokes. *Am. J. Spyhilis*, 1919, iii, 240.

The following conclusions are presented relative to the diagnostic value of lowered bone conduction in spyhilis:

1. The so-called lowered bone-conduction test (reduction in conduction of sound by bone as compared with otherwise normal hearing) was positive in 78 per cent of known syphilitics in the series studied.
2. From the otologic standpoint the test is of value only if a complete hearing test is made.
3. The efficiency of the test varied greatly in different types of syphilis, being at its best in late cutaneous syphilis (100 per cent), latent syphilis (80 per cent), and syphilis of the central nervous system (80 per cent). It had almost no value in osseous lues, and the results in early syphilis were inconclusive (too few cases). A negative Wassermann test combined with a negative bone conduction test is strong evidence of the absence of syphilis.
4. The test agreed with the positive or negative diagnosis of syphilis in 67 per cent, and disagreed in 33 per cent.
5. The test was positive also in 48.7 per cent of patients in whom syphilis could apparently be excluded.
6. On the whole, therefore, the test has only a restricted value as a diagnostic aid owing to its high factor of error.